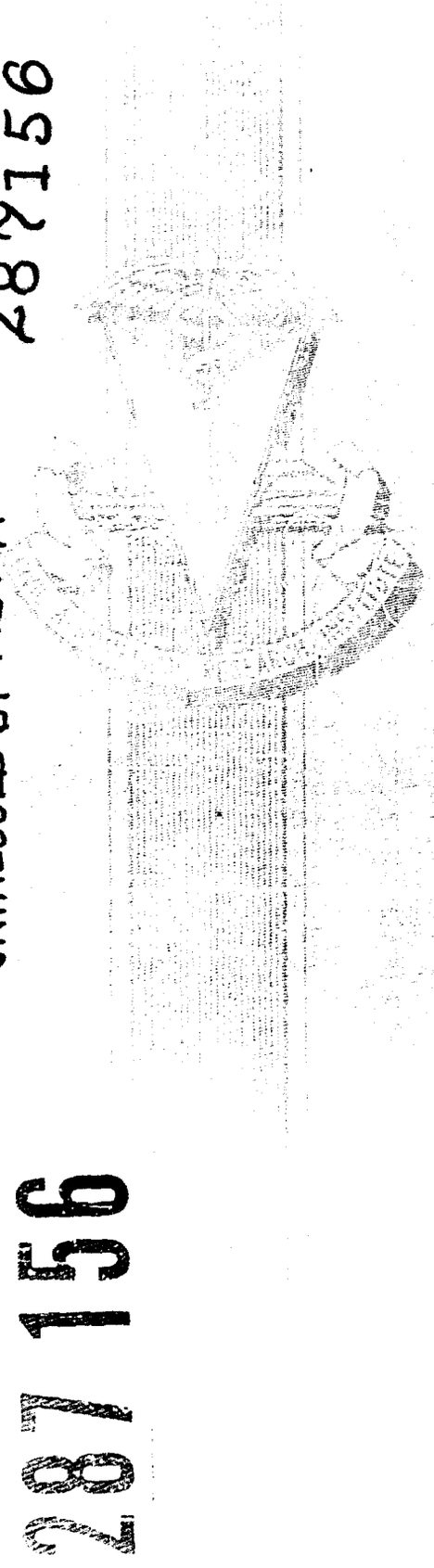
AD 287 156



DETERMINATION OF CENTERS OF GRAVITY OF MAN

62-14

FEDERAL AVIATION AGENCY
AVIATION MEDICAL SERVICE
AEROMEDICAL RESEARCH DIVISION
CIVIL AEROMEDICAL RESEARCH INSTITUTE
OKLAHOMA CITY, OKLAHOMA

August 1962

DETERMINATION OF CENTERS

OF GRAVITY OF MAN

JOHN J. SWEARINGEN

Chief, Protection and Survival Branch

62-14

FEDERAL AVIATION AGENCY
AVIATION MEDICAL SERVICE
AEROMEDICAL RESEARCH DIVISION
CIVIL AEROMEDICAL RESEARCH INSTITUTE
OKLAHOMA CITY, OKLAHOMA
August 1962

DETERMINATION OF CENTERS OF GRAVITY OF MAN

JOHN J. SWEARINGEN

ABSTRACT

Data are presented concerning the location of the center of gravity of the adult male in various body positions and the ability to shift the c.g. voluntarily with various body motions. Maximum possible shifts of the c.g. from that of an erect standing posture were found to be 11½ inches toward the head, 10 inches toward the feet, 8 inches anteriorly, 4½ inches posteriorly and 4½ inches laterally.

INTRODUCTION

The data presented in this report concerning the location of the center of gravity of the adult male and the ability to shift the c.g. with various body motions were originally published as a Civil Aviation Medical Research Laboratory Report in 1953 (CAA Project No. 53-203). During the past nine years these data have proved most useful in studies to determine (1) effective restraint devices for protection against crash forces, (2) flight and balance characteristics of one-man helicopters, (3) design of flotation equipment, (4) orientation in falls and parachute jumps, (5) capsule stability, and (6) flying platform characteristics.

With the advent of the space age it is felt that these data deserve wider distribution as they will have obvious application in the design of artificial gravity fields, space work capsules for assembling space stations, lunar and planetary landing equipment, and locomotion devices on planets with gravitational fields greater or less than one g.

For these reasons the author is taking the liberty of republishing the data as a CARI report.

EQUIPMENT AND PROCEDURE

A number of different techniques for locating and recording the c.g. were tested and the following chosen for use in this study. The equipment consists essentially of five platforms (Fig. 1a) mounted one above the other. The top platform, which supports the subject, consists of an adjustable seat with arm and foot rests. The bottom of the seat, the foot rest and the arm rests are adjustable to different angles and can be counterbalanced in each position by a sliding weight on the back of the seat. This adjustable chair can be rotated about a horizontal axis from the horizontal through approximately 20° to a second position and locked in position. The second and third platforms slide horizontally at right angles to one another by means of jack screws. Each of these platforms also has its own counterbalance system, keeping the equipment as a whole in perfect balance regardless of position with reference to the bottom platform. Details of these counterbalance systems are shown in Fig. 2. The fourth platform is separated from the bottom platform by means of a ball and socket joint in the center and four electrical contact points, one at each

corner of this four foot square platform. Each of these contact points lights a light in its corner if the platform is tilted in that direction. Hence, the platform may be assumed to be in balance when all four lights are out. A horizontal scale with one-fourth inch increments was mounted on the supporting structure of the tilt chair with its zero in vertical alignment with the reference point on the seat.

A vertical cable was stretched taut from the ceiling to the base platform in front of the horizontal scale and a camera sight set up approximately ten feet from the platform. The camera sight, vertical cable and ball and socket fulcrum were in alignment. A similar arrangement was placed at the end of the platform for reading lateral displacements of c.g. The subject was then placed in the supporting structure with the seat back in the horizontal position (Fig. 1a), the equipment balanced by means of turning the jack screws and a reading taken on the horizontal scale. This reading represents the vertical height of the c.g. of the subject above the reference point when the subject is in normal upright sitting posture. The seat was then tilted approximately 20°, locked in position (Fig. 1b) and rebalanced. The reading from the horizontal scale obtained as described above was then set on the base leg of a special adjustable T-square and the base of this T-square placed upon the seat back with the zero of the square at the line of intersection of the seat back and seat bottom. A second reading (the horizontal distance of the c.g. of the subject from the reference point) was then taken through the camera sight where the perpendicular member of the adjustable T-square intersected the vertical cable. By this method the location of the center of gravity of the subject was determined directly with reference to the seat.

Although the total weight of the equipment and subject on the fulcrum may have reached 800 pounds, the equipment was sensitive enough that the weight of a silver half dollar placed on one corner would light the light in that corner. The breaker-over distance the platform had to be moved by turning the jack screw to turn out one pair of lights and turn on the opposite pair was about one-eighth inch. For this reason, accuracy of reading is believed to be within one-eighth of an inch with repeated readings on the same subject not varying more than one-fourth inch. The latter variation is probably caused by slight differences in the position of the subject as he remounted the platform.

During this study it became apparent that any point on the pelvic structure was chosen as a reference point the centers of gravity of all men fell in a very small area. For this reason all vertical distances to the centers of gravity are measured from the inferior spine of the ischium. Horizontal measurements are either from the anterior or posterior plane of the body, depending upon the type of motion involved. For convenience of discussion the sixty-seven different body positions studied are divided into three groups: sitting, maximum displacement of c.g., and the effects on the c.g. of adding various weights to the body.

THE SAMPLE

The number of subjects tested was limited by the large number of positions being studied. Only five men were tested in all sixty-seven positions, but they were carefully chosen to include a wide range of body sizes and weights. Authropometric measurements of these subjects are presented in Table Ia. In addition to the five tested in all positions, an additional twenty-seven men were check tested in one sitting and one standing position. In the sitting position (Fig. 4, B—sitting with hands in lap) the centers of gravity of all but one subject (97%) were found to fall within the range established for the original five subjects. In the standing position, all but three (91%) fell within the established range. An analysis of the anthropometric measurements of these four subjects (Table Ib, subjects number 12 sitting and 7, 10, and 24 standing) shows the very abnormal distribution of weight between the trunk and legs. Subject number 12 has the major portion of his 202 pounds in his trunk with very short, light legs. His center of gravity falls 3/4 inch above the established range for the sitting position. Subject number 7 has extremely long, heavy legs and a short, light trunk, causing his c.g. to fall 7/8 inch below the established range for the standing position. Body characteristics of subjects 10 and 24 cau

their c.g. to fall 1 inch above the established range for the standing position. Their anthropometric measurements are presented in Table Ib.

SITTING

Studies were made on three different sitting groups. The first group (Fig. 4) represents man in the normal sitting position; that is, trunk erect, thighs 90° to the trunk and legs 90° to thighs, and presents data showing the effects upon the center of gravity of moving one and both arms to various positions. In addition to the arm movements, two tests were made to show the shift of center of gravity when the trunk was flexed forward from the sitting position. The vertical height of the center of gravity was measured either from the seat bottom or from the ischium, as it was assumed that the ischium was in contact with the seat bottom. Horizontal distances to the c.g. in these tests were measured from the seat back.

The second group (Figs. 5, 6 and 7) concerns itself with the study of various pilot positions and shows the shift of center of gravity if the arms are moved to various positions for operation of controls with the legs at the comfort angle [1,2] where the knees are 110°, ±5°, and, in addition, two extreme positions for the feet, one in which the feet are back under the chair and one where the legs are fully extended.

The third group (Fig 8) represents the commercial airline passenger in the full reclining position and shows the displacement of the center of gravity of the body for the passenger when the arms are moved to various positions and when the feet are on the floor or on the foot rest of the seat immediately in front. In this position the seat back makes an angle of 115° with the seat cushion. However, since both the trunk and pelvis are reclining at this angle, these tests and measurements were made by dropping the legs to the 115° angle. It must be noted here that vertical distances of the center of gravity were measured from the ischium parallel to the plane of the subject's back, while horizontal distances of the c.g were perpendicular distances from this plane. In F of Fig. 8 the passenger is not reclining but is assuming one position in a current study to determine the best position for passenger the event of a crash.

MAXIMUM DISPLACEMENT OF C.G.

In this study of shift of the center of gra with maximum movements of the body pelvis remains fixed and all movable body p were shifted on the pelvis in a given direct In the first group (Fig. 9) the shift of the c ter of gravity accompanying various *ante* movements of body parts was studied and corded. This included flexing the head ward, extending both arms straight forw flexing the trunk forward (note the sn amount of flexion of the trunk when pelvis is held rigid), extending the legs strai forward and the final test in which all b parts were moved in unison to the maxim anterior position. The center of gravity v measured as the vertical height above the chium and the horizontal distance from posterior body plane.

For the *posterior* motions (Fig. 10) t similar to those described in the anterior gro were made. These individual tests were ma to determine the effect on the center of grav for posterior motions of head, arms, trunk, l and all body parts moved in posterior directi Again the center of gravity was measured v tically from the ischium and horizontally fr the anterior body plane.

In the study of *lateral* shifts of c.g. (Fig. 1 individual tests were made for location of t center of gravity with the head flexed to t side, with the left arm extended laterally, wi the right arm across the chest, with the he and trunk flexed to one side, with the left l in maximum abduction, with the left leg a ducted and the right leg adducted, and a fir test with all body parts moved laterally as f as possible. In all tests the pelvis was n moved and the center of gravity was measur vertically from the ischium and horizontal from the mid-sagittal plane.

In tests to move the center of gravity as f as possible toward the head (*cephalac* (Fig. 12) individual tests for both arms e tended over the head and for both legs flex toward the head as well as one final test, wit both legs and both arms in maximum cephala

direction, were made. In these tests the center of gravity was measured vertically from the ischium and horizontally from the posterior body plane.

Only two tests were made for shifting center of gravity toward the feet (*caudad*) (Fig. 13), one with the subject standing with the trunk flexed as far as possible without extending the arms and the second with the arms extended. Here the pelvis was allowed to rotate but the vertical distance of the center of gravity was measured from the position of the ischium before flexion of the trunk in order to show the total caudad shift due to these movements. The horizontal distance of the c.g. was measured from the posterior body plane.

Finally, tests to determine shifts of center of gravity accompanying maximum abduction of arms and legs were made (Fig. 14 and 15). Individual tests were made to determine the c.g. for abduction of the arms, for abduction of the legs and for simultaneous abduction of arms and legs. For reference, the results of these tests are presented first showing the shift of the c.g. in the free body as measured from the ischium and secondly the shift of the c.g. of man standing giving vertical height of the c.g. from the ground.

ADDITION OF WEIGHTS TO BODY

Studies were made to locate the center of gravity of man sitting and standing with a twenty pound pack on his back (Fig. 16), with the center of gravity of the pack 18-5/8 inches above the ischium and 6 inches posterior to the back. The center of gravity of man wearing this pack in the two positions studied was found experimentally on the balancing equipment and then checked by mathematical calculations, using data previously obtained in this study for the center of gravity of man without the pack. We were pleased to find that the calculated and the experimental data checked within one-fourth inch. The significance of these tests is obvious as they show that the data presented in this report may be used as a basis for mathematical calculations of location of the center of gravity of man in various positions with the addition of various weights to the body; for example, parachut ack packs, chest packs, etc.

RESULTS

The results are presented bot graphical (Figs. 4 through 16) and tabu Tables II through XIV) form with sma agramatic figures representing the body p ns of the subjects. For any one position t ometrical average of the centers of grav f all five subjects is shown as a black n Figs. 4 through 16 along with an arc of le which, if completed, would include the al centers of gravity of all subjects.

DISCUSSION AND CONCLUS

It will be noted from a study se graphs that the variation between subje any one position is sometimes greater th e shift of the center of gravity of the gro te to any particular motion. Fig. 3 prese tual centers of gravity of each of the fi ting subjects for three different arm positi nd shows the location of the geometrical a es of the group. It will be noted from t aph that the shifts of c.g. of all subjects f a definite pattern. The completed circl Figs. 4, 5, 6, and 7 enclose areas that inclu subjects and all arm positions. In Fig this area has a two inch radius while a rad one and one-half inches suffices in Figs. 5 nd 7.

Analysis of tests of maximun ft shows that man is capable of shifting hi roughly 11-1/2 inches toward the head 12), 10 inches toward the feet (Fig. 13) ches anteriorly (Fig. 9), 4-1/2 inch osteriorly (Fig. 10), and 4-1/2 inches later Fig. 11) from that of an erect standing p .

The maximum shift of c.g. a panying the movement of all body parts i given direction is not the sum of the sh roduced by moving each part separately.

This study shows that in spite he wide variety of body sizes and mass ributions there is surprisingly little variatio the location of the body c.g. when mea from a reference point on the pelvis. In en body

position the c.g. of at least 90% of the adult male population falls within a sphere 2 inches in diameter.

REFERENCES

1. Elbel, E. R., Leg strength and leg endurance in relation to height, weight, and other body measurements, Project No. 318, Report No. 1, 27th AAF Base Unit, AAF School of Aviation Medicine, Randolph Field, Texas, 15 August 1945.
2. Swearingen, J. J., Determination of the most comfortable knee angle for pilots, Civil Aeronautics Medical Research Laboratory, Project No. Biotechnology 3-48, Report No. 1.

TABLE I

Anthropometric Measurements* of Original 5 Subjects

	J.	B.	M.	N.	T.
1. Age	39	39	29	60	39
2. Weight	152	152	225	177	113.25
3. Stature	68	72	69.75	69.5	64.75
4. Sitting Height (Anthro.)	34.75	37.5	36.5	37	33.5
5. Trunk Height	23	24.5	24	22.5	23
6. Eye Level (Anthro.)	30	32.25	31	31.25	28.5
7. Buttocks Knee	23	24.5	24.5	23.5	22.5
8. Patella Height	21	22.25	22	20.75	19.75
9. Abdominal Girth	30.25	29	38	35	26
10. Thigh Circumference	18.75	18	24	20.75	15.5
11. Chest Depth	8	8.25	10.75	9.5	6.75
12. Abdominal Depth	7.75	7.5	10	9.5	6.5

*Weight in pounds; all other in inches

TABLE Ib

Anthropometric Measurements of Subjects Used for Check Tests

Subject No.	Age	Weight	Stature	Sitting Ht. (Anthro.)	Trunk Height	Eye Level (Anthro.)	Buttocks Knee	Patella Height	Abdominal Girth	Thigh Circumference	Chest Depth	Abdominal Depth
1	39	165.5	68.5	36.25	24	32	24	20	30	18	9.75	9.25
2	53	205	72	38	23.5	33.5	25.75	22.25	34.5	19	11.75	10.25
3	39	216	70.5	36.5	23	32	25.5	22	41	19.5	12.5	12
4	41	118	69.75	35.5	21.5	31	24.5	21.5	28	15.5	9	7.5
5	36	146.5	68.5	35.75	24	32	23	20	31	18	8.5	8
6	50	174.5	64.5	32	22	29.5	22.25	19	36	20.5	10.5	9.5
7	41	164	70.75	32.25	21.75	30	25.5	22.5	31	20.25	9.25	8
8	39	151	74.75	36	25	33.5	25	22.75	28	18.5	9.25	7.25
9	35	224.5	70	36	25	32.5	23.5	20.75	37.5	23.5	11	10.25
10	38	161	61	31.25	22	28.5	19.75	18	36.25	29.5	11	10.75
11	57	160	70	36	21.5	30.25	23.75	21.5	33.5	19	9	9
12	35	202.25	67.75	36.25	23.5	31.5	22.5	19.5	36	22.25	10.25	10.25
13	29	133.	67.5	35.25	22.5	30.75	21.75	20.25	31.75	17	8.25	7.25
14	43	175.75	67.5	35.75	23.25	31	22.5	20.5	37	20	10.25	9.75
15	44	153.5	69.25	36	24.5	32.5	23.5	20.75	29.75	19	9	7
16	43	145.5	66.25	35.5	24.25	31.5	22	19.5	31.5	19.25	8.25	8.5
17	35	150.5	65	34.25	23.25	30.5	21.75	18.75	32.75	20	8.5	8
18	33	135.5	66.5	34.75	23	30.5	22.5	19.5	28	18	8.5	7.5
19	29	167.25	73	38	25.25	32.75	24	22	30.5	29.25	10	8
20	33	137.5	68	35.5	23.5	30.5	23.5	20.25	27.75	18	7.5	7.25
21	33	167.25	72.5	38	24	33	24.25	22	32.25	20	8.5	8
22	45	194.5	68.75	36.75	23.5	32	22.5	20	37	21	9	10.5
23	29	134.25	69	37.25	24.25	32.75	21.5	20	24.75	18.5	8.25	6.5
24	35	177	69.5	38	23	31.75	23.5	20.25	31.75	21	9.25	9
25	31	153.25	69.25	35.25	21.5	30	24.75	21	29.5	18	9	8
26	24	147.25	72.5	37	23	31.5	24.25	22.5	28.75	18.5	9	7
27	30	137.75	69	36.75	24	31.75	23.25	20	25.5	18	7.5	6.5

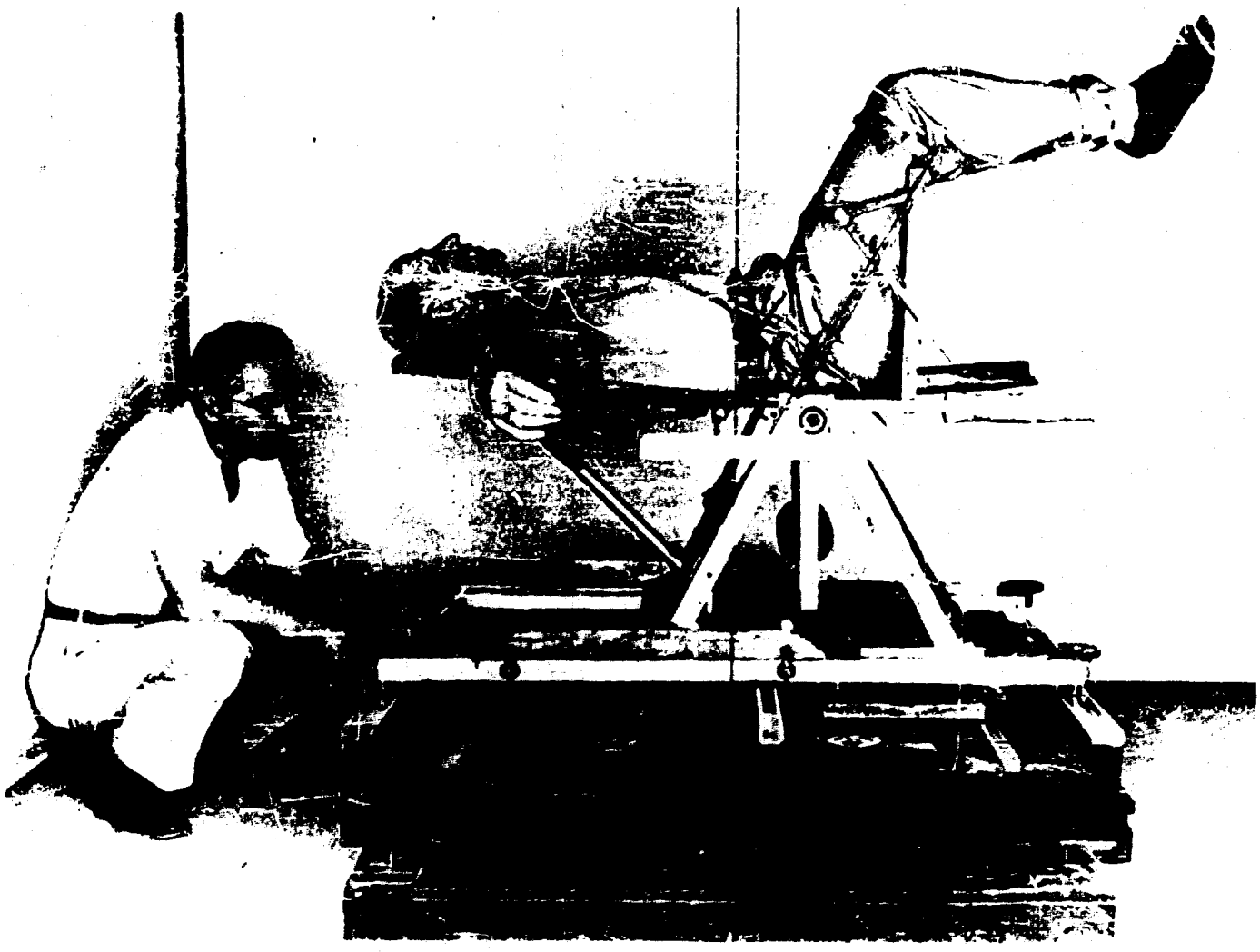


FIGURE 1a. Technique of reading vertical distance of C. G. from reference point.

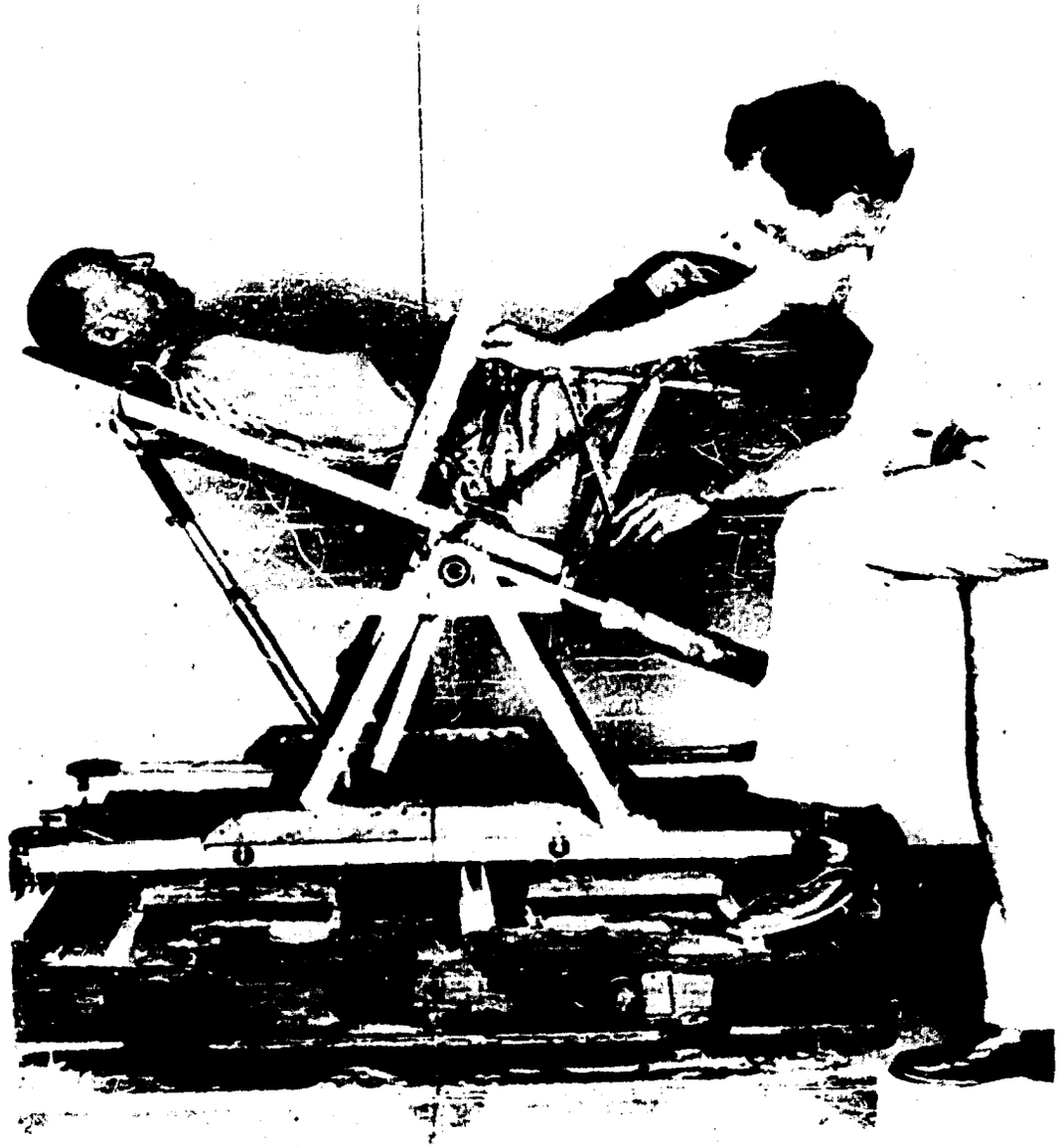


FIGURE 1b. Technique of reading horizontal distance of C. G. from reference point.

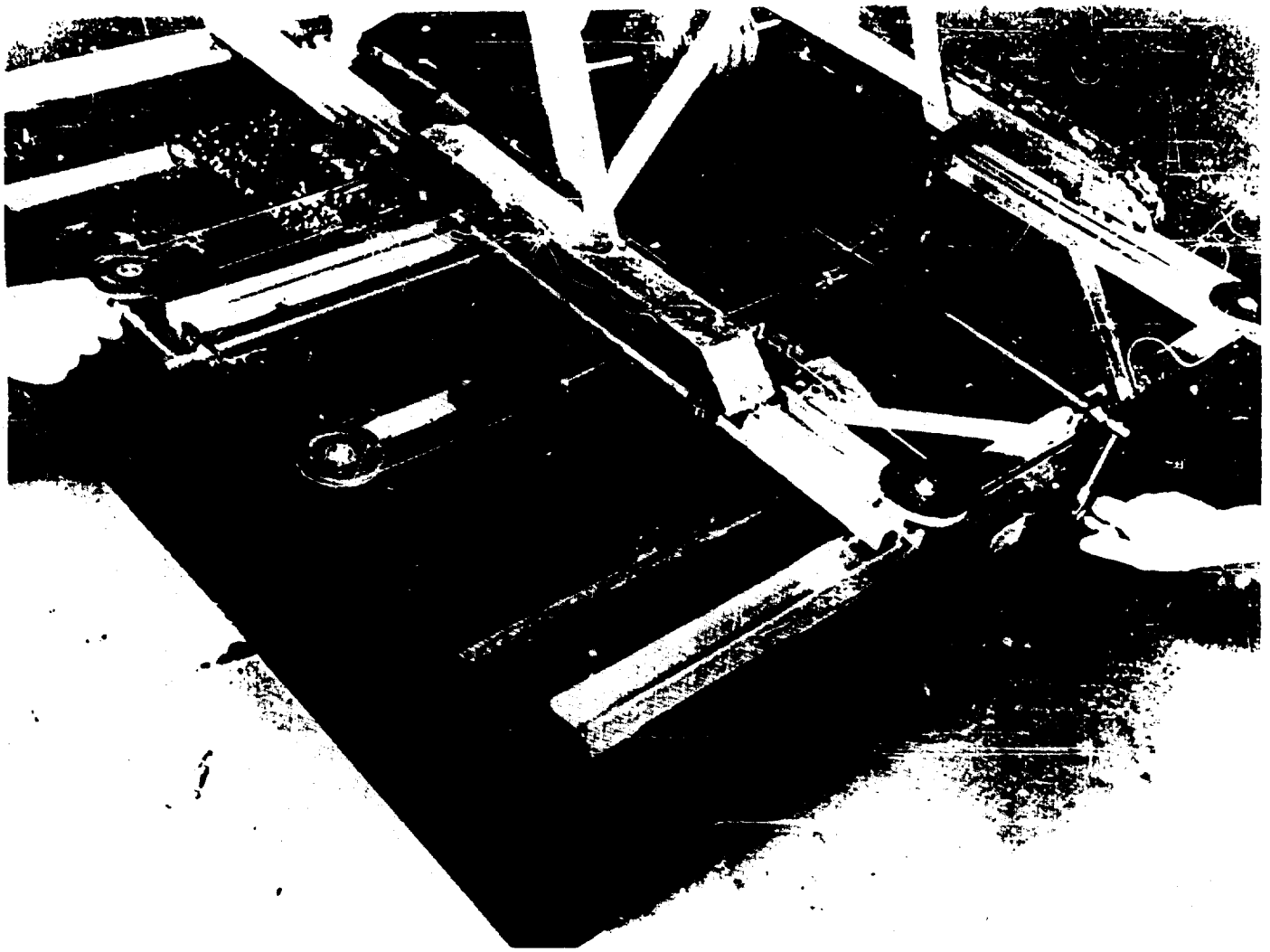


FIGURE 2. Details of counterbalance system.

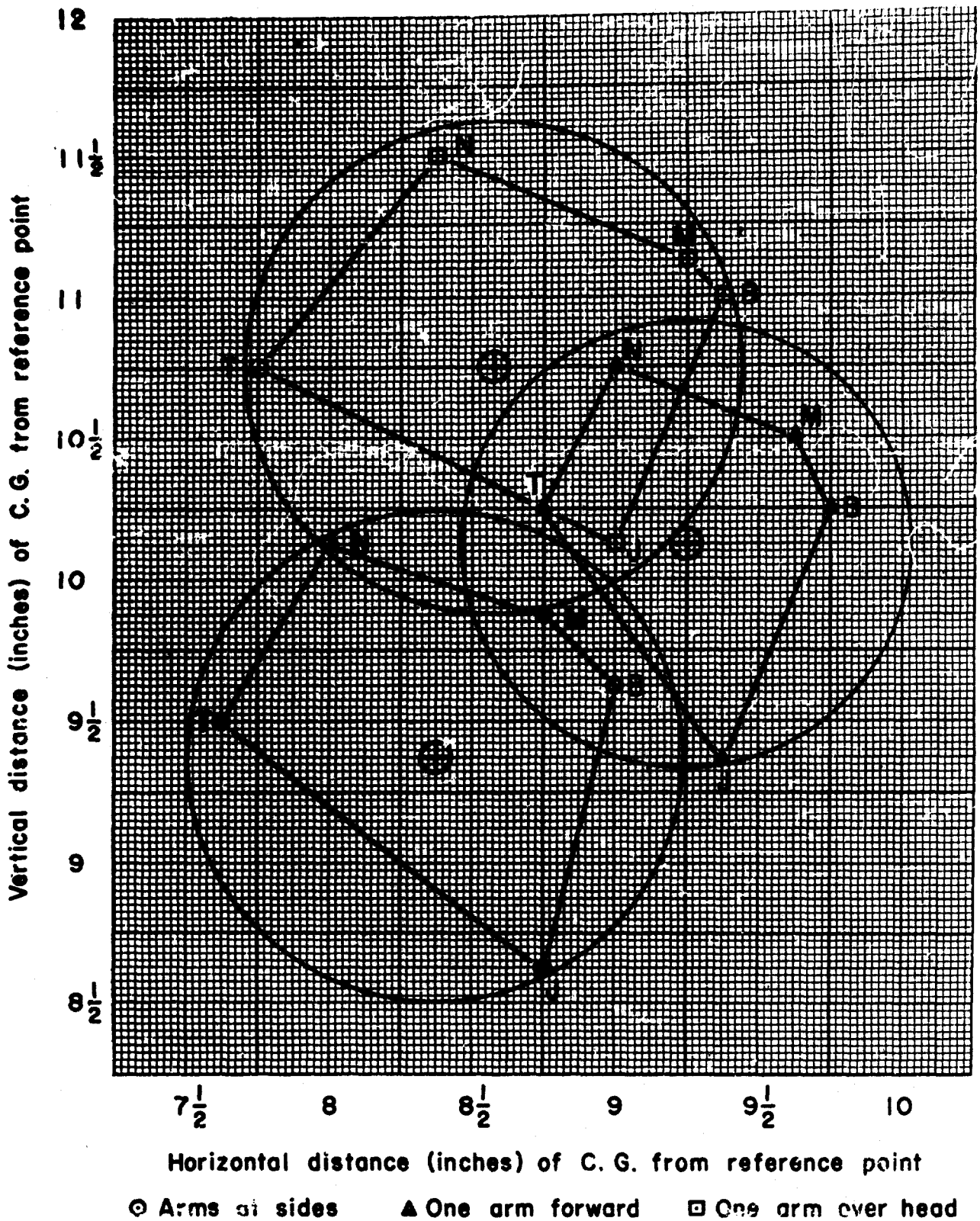
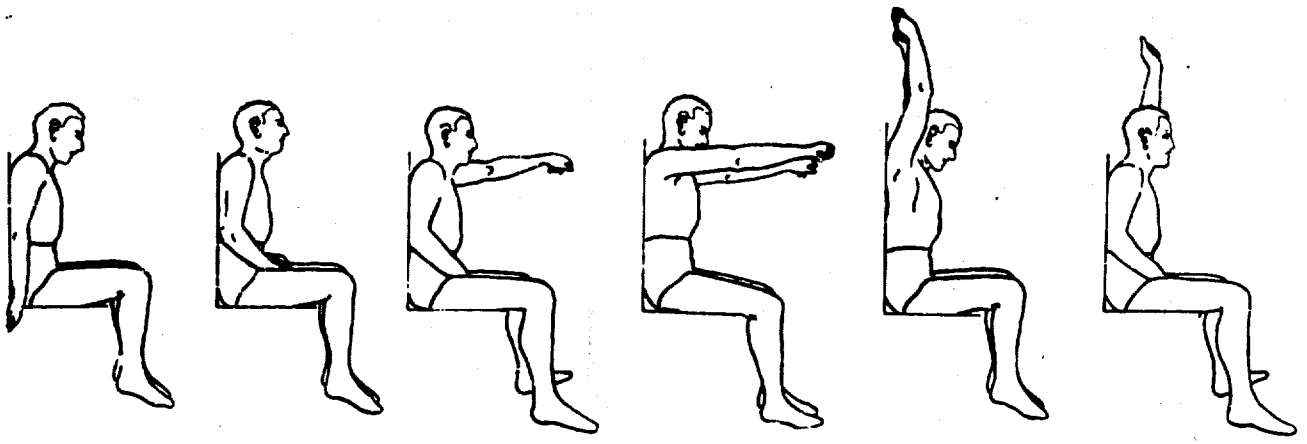


FIGURE 3. Centers of gravity of all five subjects for three arm positions.

TABLE II

Sitting With Seat 90° to Back, Legs 90° to Thighs

	Body Position	Location of Av. c. g.	Horizontal & Vertical Range For Subjects
A.	Both arms down at sides	(8¾, 9¾)	± ¾"
B.	Both hands in lap	(8¾, 9¾)	± ¾"
C.	One arm forward, one hand in lap	(9¾, 10¾)	± ¾"
D.	Both arms straight forward	(9¾, 10¾)	± ¾"
E.	Both arms extended over head	(8¾, 12)	± ¾"
F.	One arm over head, one hand in lap	(8¾, 10¾)	± ¾"
G.	Both arms extended laterally	(8¾, 10¾)	± ¾"
H.	One arm extended laterally, one hand in lap	(8¾, 10¾)	± ¾"
I.	Both arms extended posteriorly	(8, 10¾)	± ¾"
J.	Trunk flexed on thighs, arms extended forward	(15¾, 5-3/16)	± 1¾"
K.	Trunk flexed on thighs, arms down	(14-15/16, 5)	± 1¾"



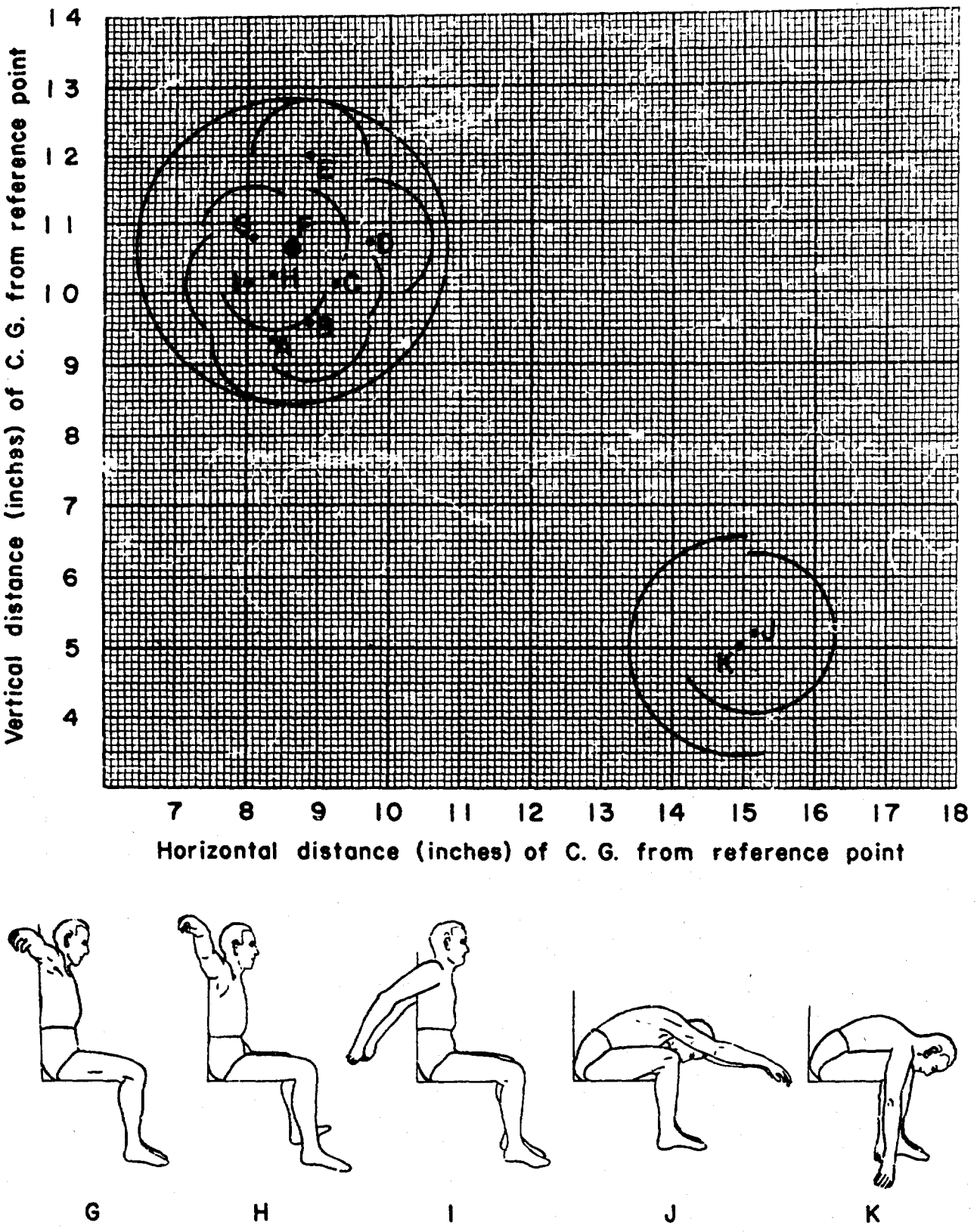


FIGURE 4. Displacement of the body C. G. by arm movements; sitting with seat 90° to back, legs 90° to thighs.

TABLE III

Sitting Back Erect, Seat 90° to Back, Legs 50° to Thighs

Body Position	Location of Av. C. G.	Horizontal & Vertical Range For Subjects
A. One hand on stick control, one on control at side of seat	(7¾, 9¾)	± ¾"
B. One hand on overhead control, one on control at side of seat	(8, 10¾)	± ¾"
C. Both hands on overhead control	(8¾, 10-9/16)	± 1"
D. Trunk flexed on thighs, arms around knees	(13¾, 4¾)	± 1"

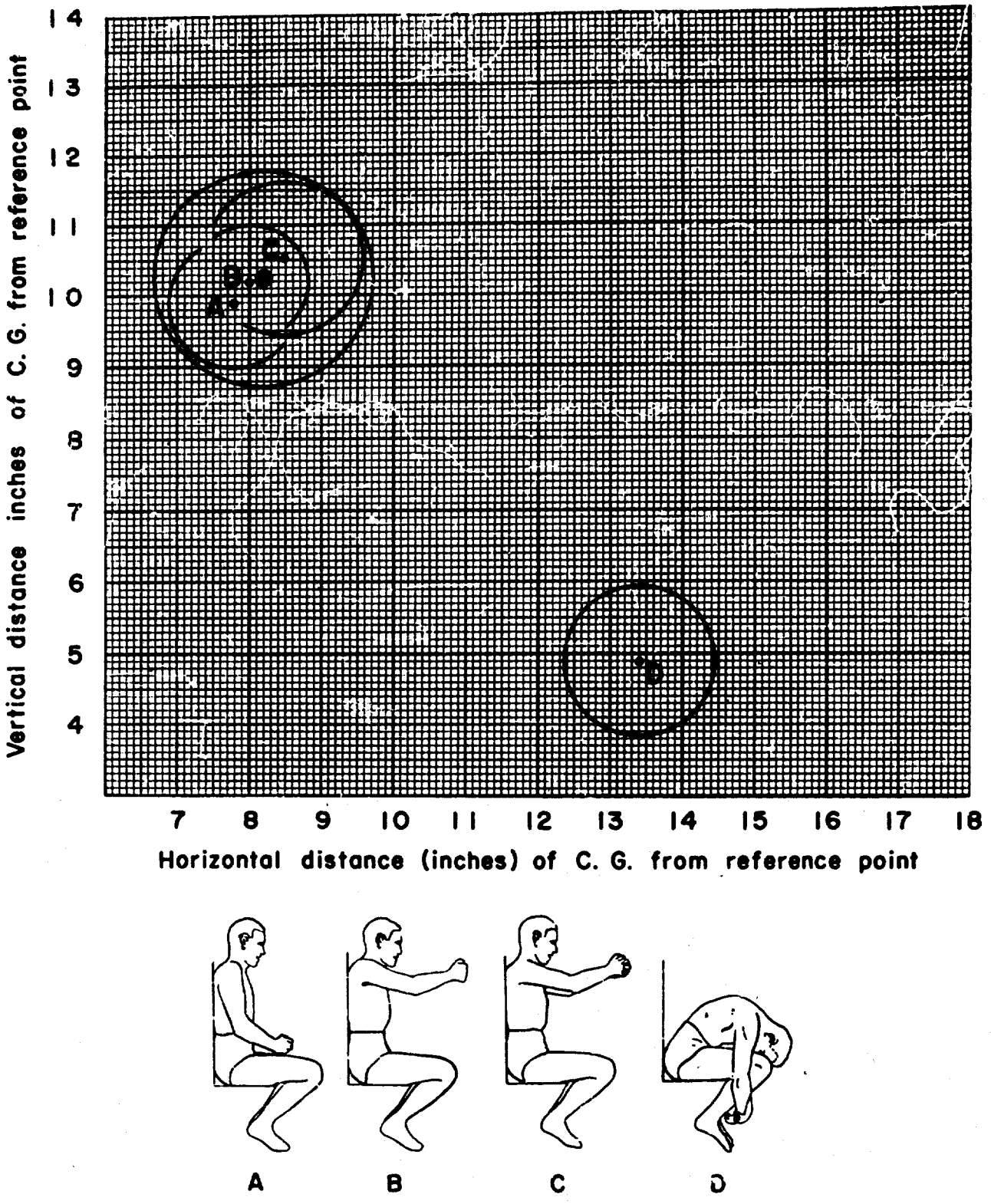


FIGURE 5. Position of body C. G. of pilot operating controls in various positions; back erect, seat 90° to back, legs 50° to thighs.

TABLE IV

Sitting Back Erect, Seat 90° to Back,
Legs 110° to Thighs

Body Position	Location of Av. C. G.	Horizontal & Vertical Range For Subjects
A. One hand on stick control, one on control at side of seat	(9-1/16, 9⅜)	± ⅜"
B. One hand on overhead control, one on control at side of seat	(9-5/16, 10⅜)	± ⅜"
C. Both hands on overhead control	(9⅜, 10-9/16)	± 1⅛"

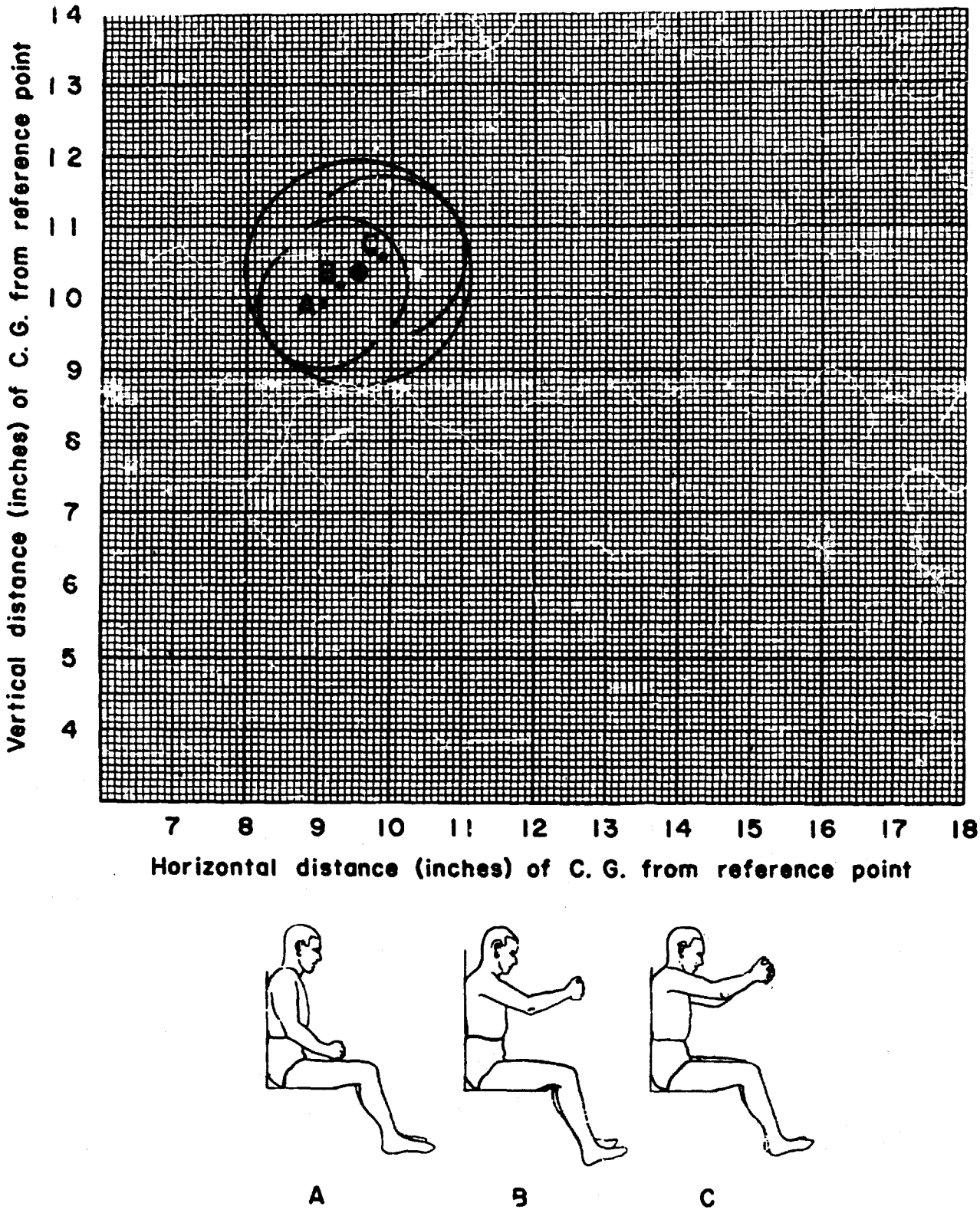


FIGURE 6. Position of body C. G. of pilot operating controls in various positions; back erect, seat 90° to back, legs 110° to thighs.

TABLE V

Sitting Back Erect, Seat 105° to Back
Legs 180° to Thighs

Body Position	Location of Av. C. G.	Horizontal & Vertical Range For Subjects
A. One hand on stick control, one on control at side of seat	(9¾, 8¾)	± 1"
B. One hand on overhead control, one on control at side of seat	(10¾, 8¾)	± 1"
C. Both hands on overhead control	(10-9/16, 8-15/16)	± ⅝"

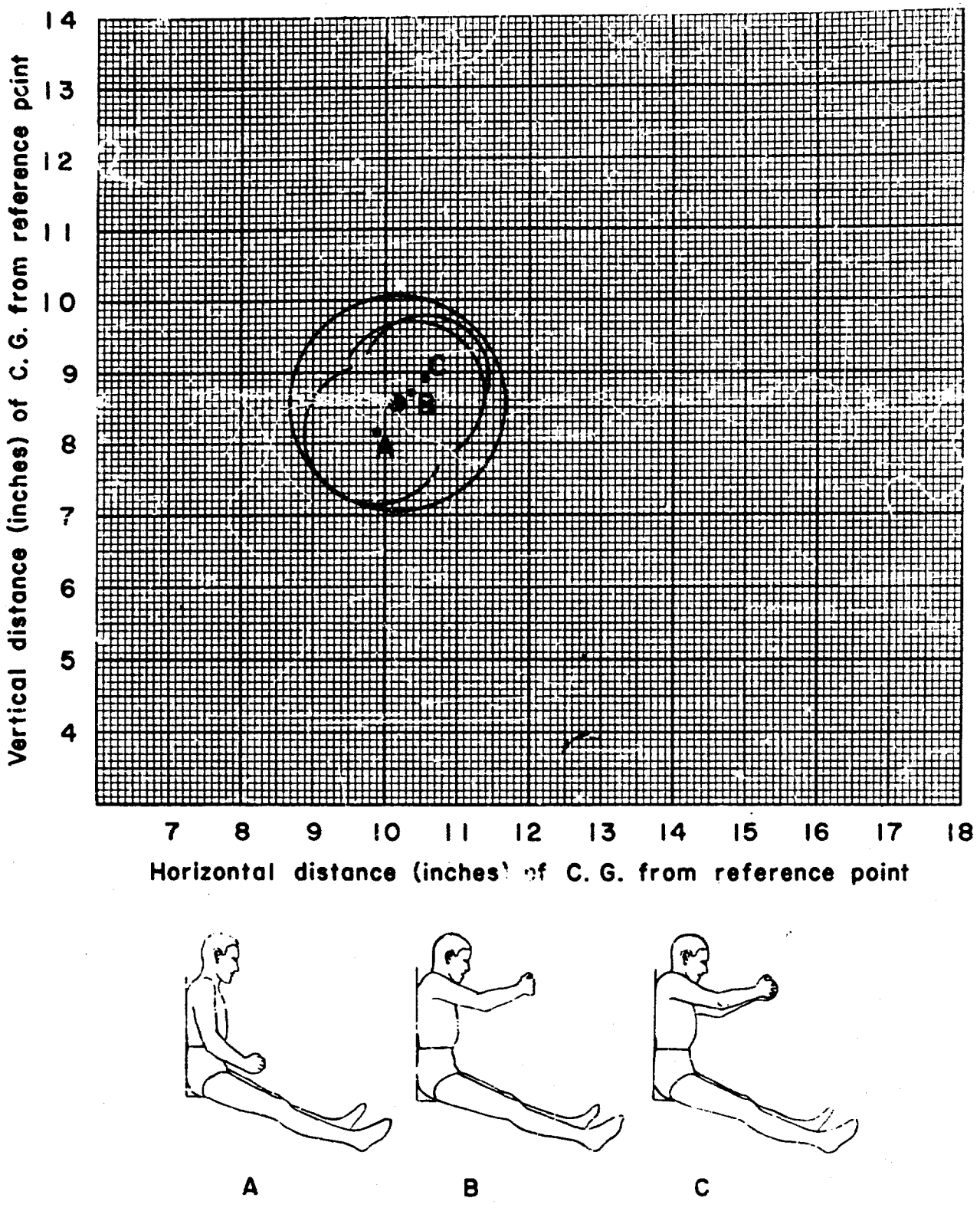
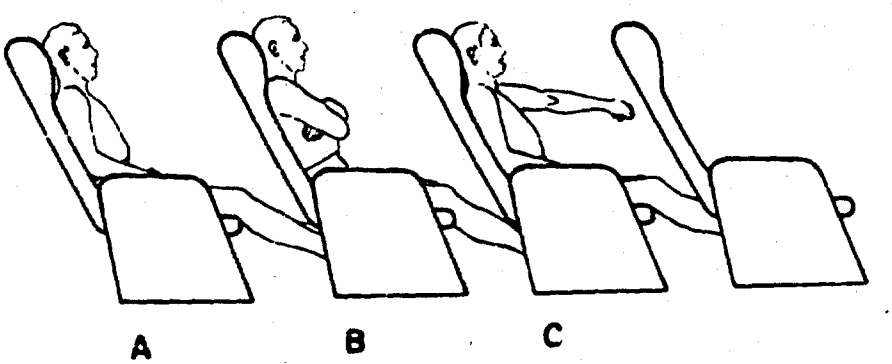


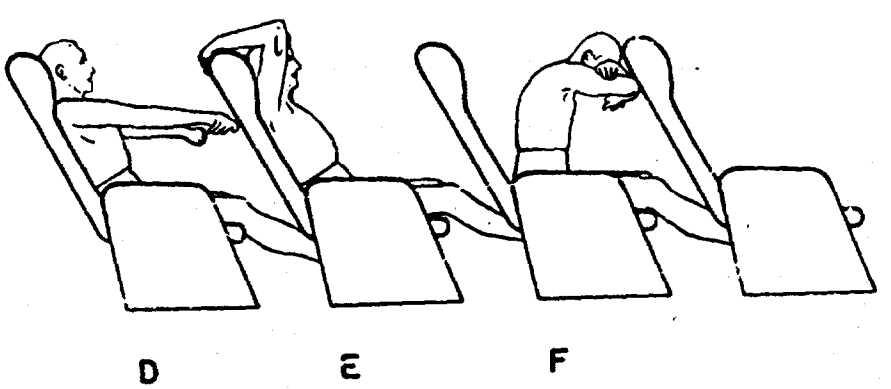
FIGURE 7. Position of body C. G of pilot operating controls in various positions; back erect, seat 108° to back, legs 180° to thighs.

TABLE VI

Displacement of Body C. G. of Commercial Airline Passengers

Body Position	Location of Av. C. G.	Horizontal & Vertical Range For Subjects
Trunk 115°, Knees 145°		
A. Hands in lap	(9¾, 7¾)	± ¾"
B. Arms across chest	(9¾, 7¾)	± ¾"
C. One arm forward	(9¾, 7¾)	± 1"
D. Both arms forward	(10¾, 8¾)	± ¾"
E. Holding to seat back	(9¾, 9¾)	± 1"
F. Head and arms on forward seat	(12¾, 10-7/16)	± ¾"
Trunk 115°, Knees 90°		
G. Hands in lap	(7¾, 6¾)	± 1"
H. Arms across chest	(8¾, 7¾)	± ¾"
I. One arm forward	(8¾, 7¾)	± 1"
J. Both arms forward	(8¾, 7¾)	± ¾"
K. Holding to seat back	(7¾, 8¾)	± ¾"





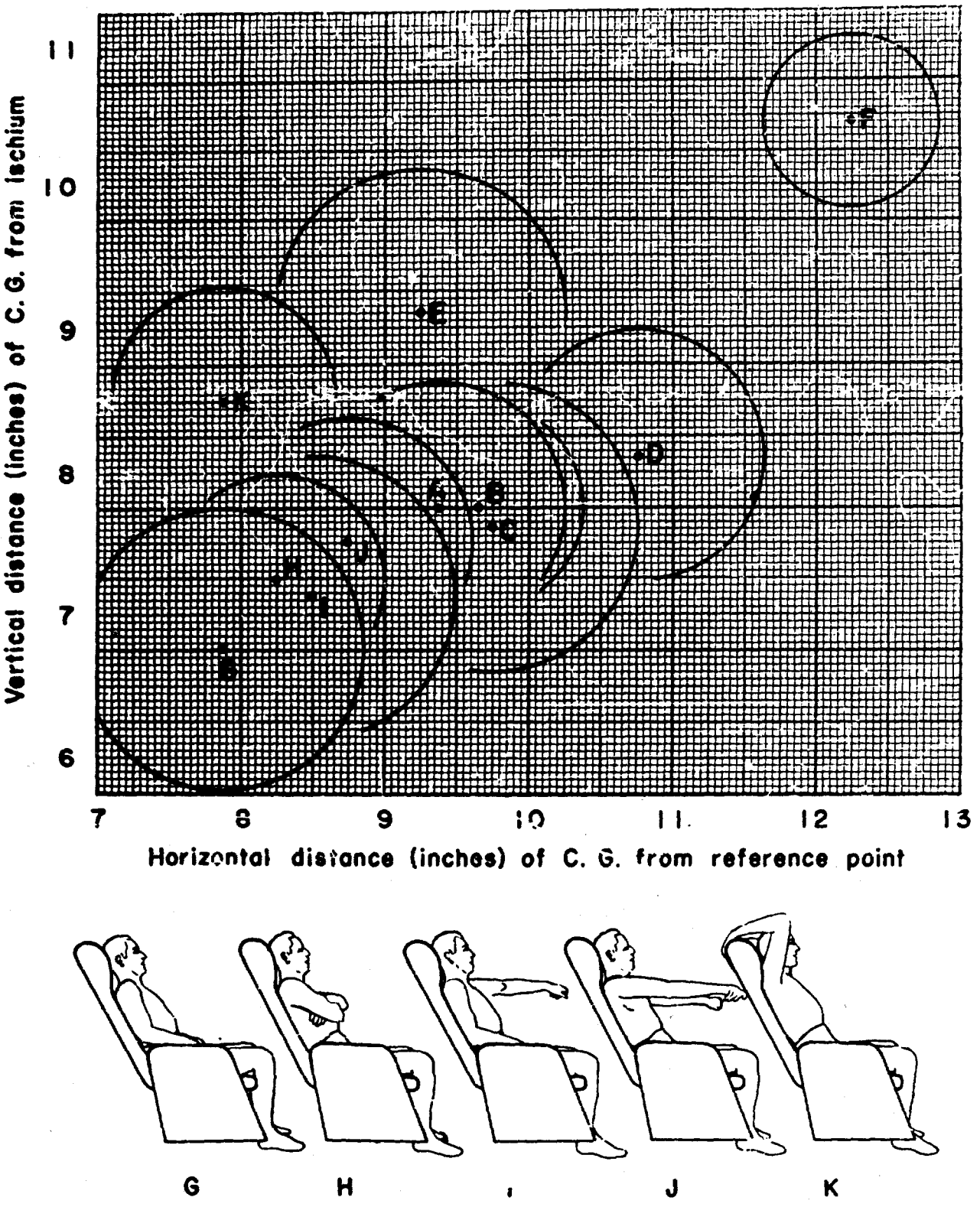


FIGURE 8. Displacement of body C. G. of commercial airline passengers.

TABLE VII

Displacement of Body C. G. by Anterior Movements

Body Position	Location of Av. C. G.	Horizontal & Vertical Range For Subjects
A. Body standing straight	(4, 5⅝)	± ⅜"
B. Head forward	(4⅝, 5⅝)	± ⅜"
C. Both arms extended forward	(5¼, 7)	± ¾"
D. Head and trunk forward	(5⅝, 4)	± 1⅛"
E. Both legs straight forward	(9, 11)	± 1¼"
F. All body parts in maximum anterior position	(12, 10⅜)	± 1⅛"

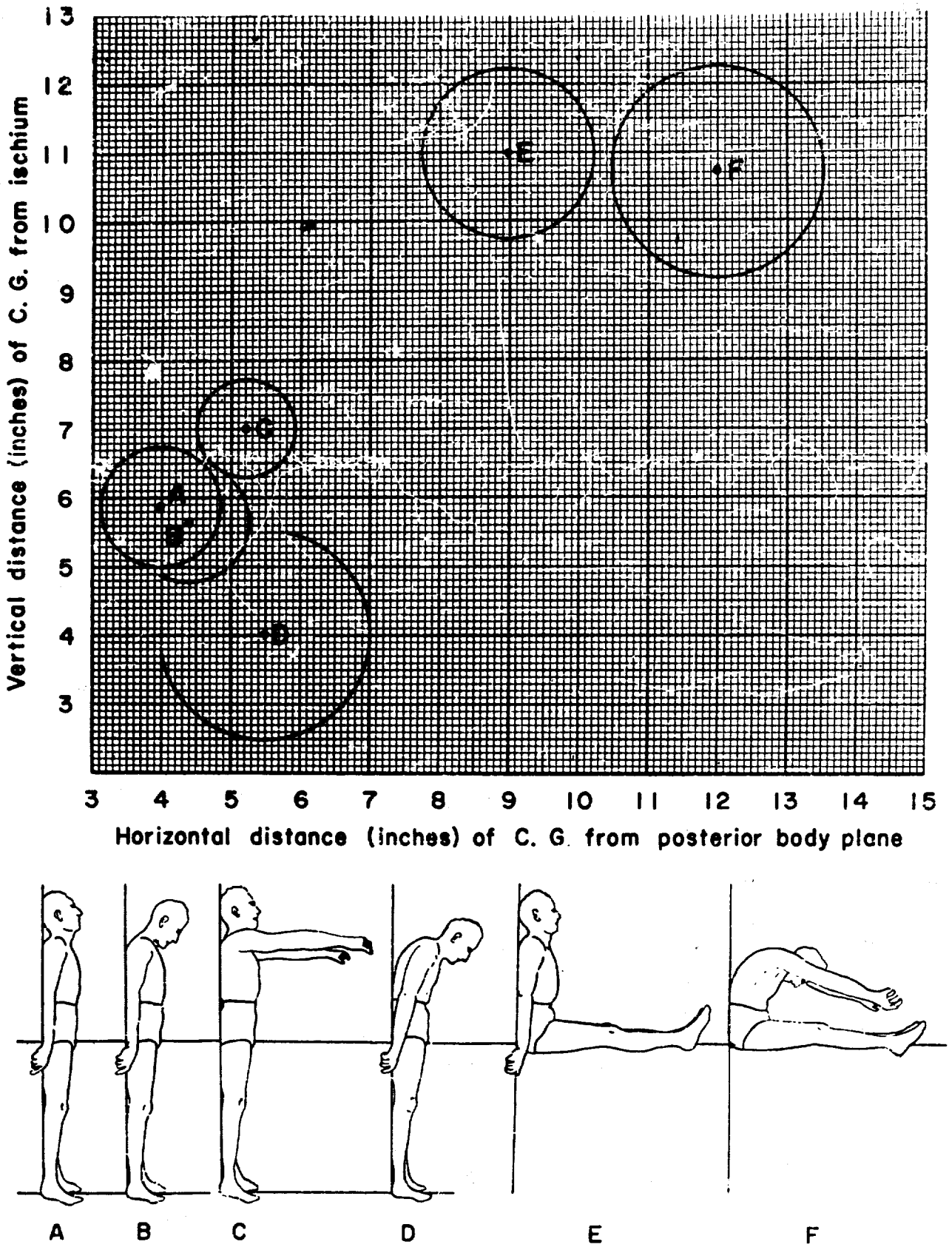


FIGURE 9. Displacement of body C. G. by anterior movements.

TABLE VIII

Displacement of Body C. G. by Posterior Movements

Body Position	Location of Av. C. G.	Horizontal & Vertical Range For Subjects
A. Standing, body straight	(5¼, 6)	± 1⅛"
B. Head back	(5⅛, 5⅝)	± 1"
C. Arms back	(5⅜, 6⅛)	± 1"
D. Head & trunk back	(7¼, 5⅜)	± 1⅛"
E. Legs back	(6⅜, 7⅛)	± 1"
F. All body parts in maximum posterior position	(9⅜, 6⅛)	± 1⅛"

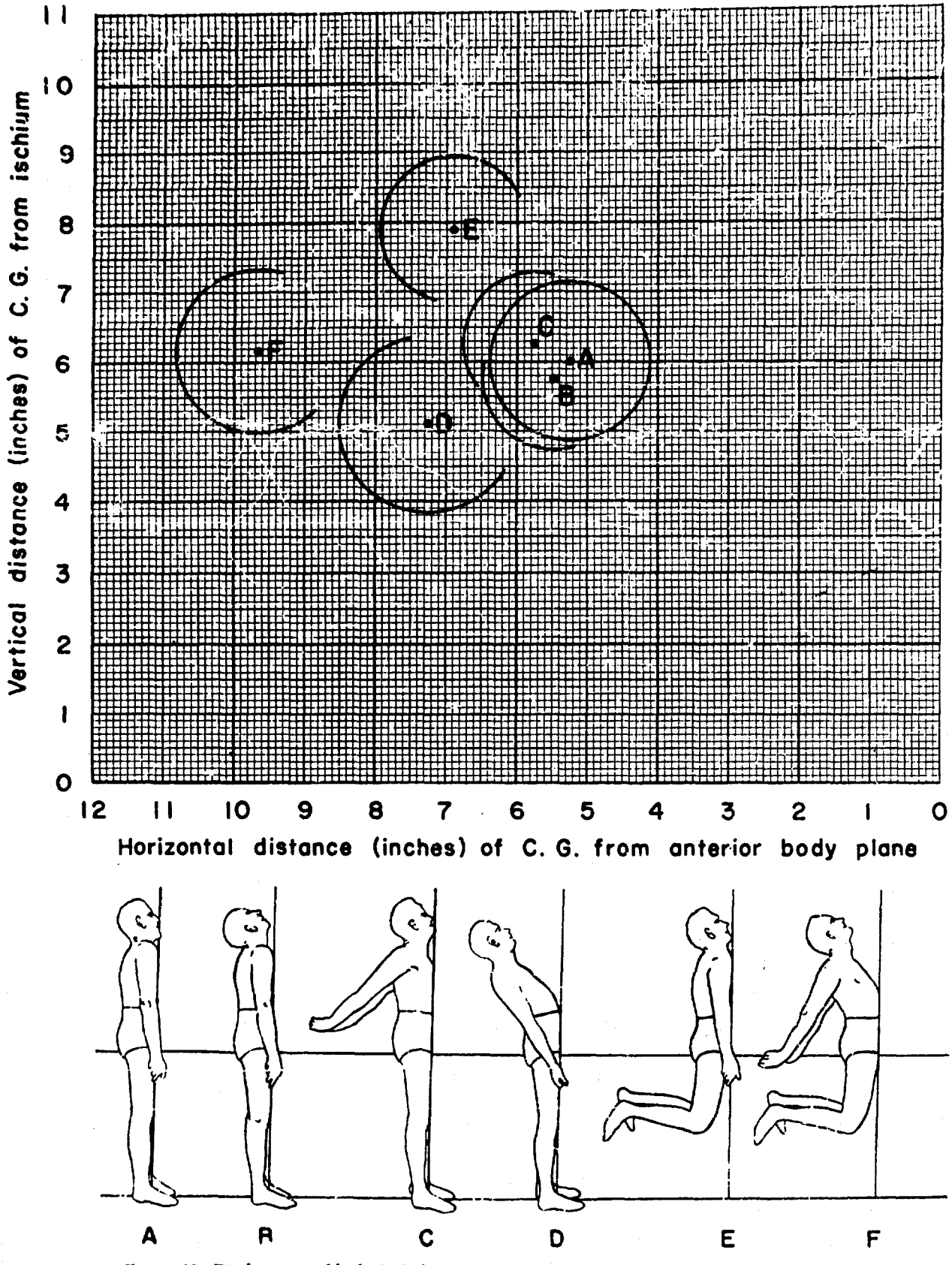
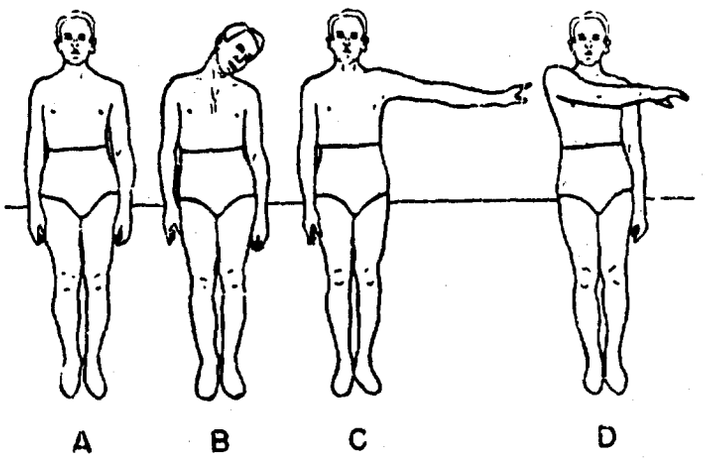


FIGURE 10. Displacement of body C. G. by posterior movements.

TABLE IX

Displacement of Body C. G. by Lateral Movements

	Body Position	Location of Av. C. G.	Horizontal & Vertical Range For Subjects
A.	Standing, body straight	(0, 5⅝)	± ⅜"
B.	Head flexed to side	(⅛, 5⅝)	± ⅜"
C.	One arm extended laterally	(⅛, 6⅜)	± ⅜"
D	One arm extended across chest	(⅛, 6⅛)	± ⅜"
E.	Head and trunk in lateral flexion	(1⅛, 5⅛)	± ⅜"
F.	One leg abducted	(1⅛, 6⅜)	± ⅜"
G.	Maximum lateral movement of both legs	(1⅛, 6⅜)	± ⅜"
H.	All body parts moved laterally	(4⅜, 7⅛)	± 1⅜"



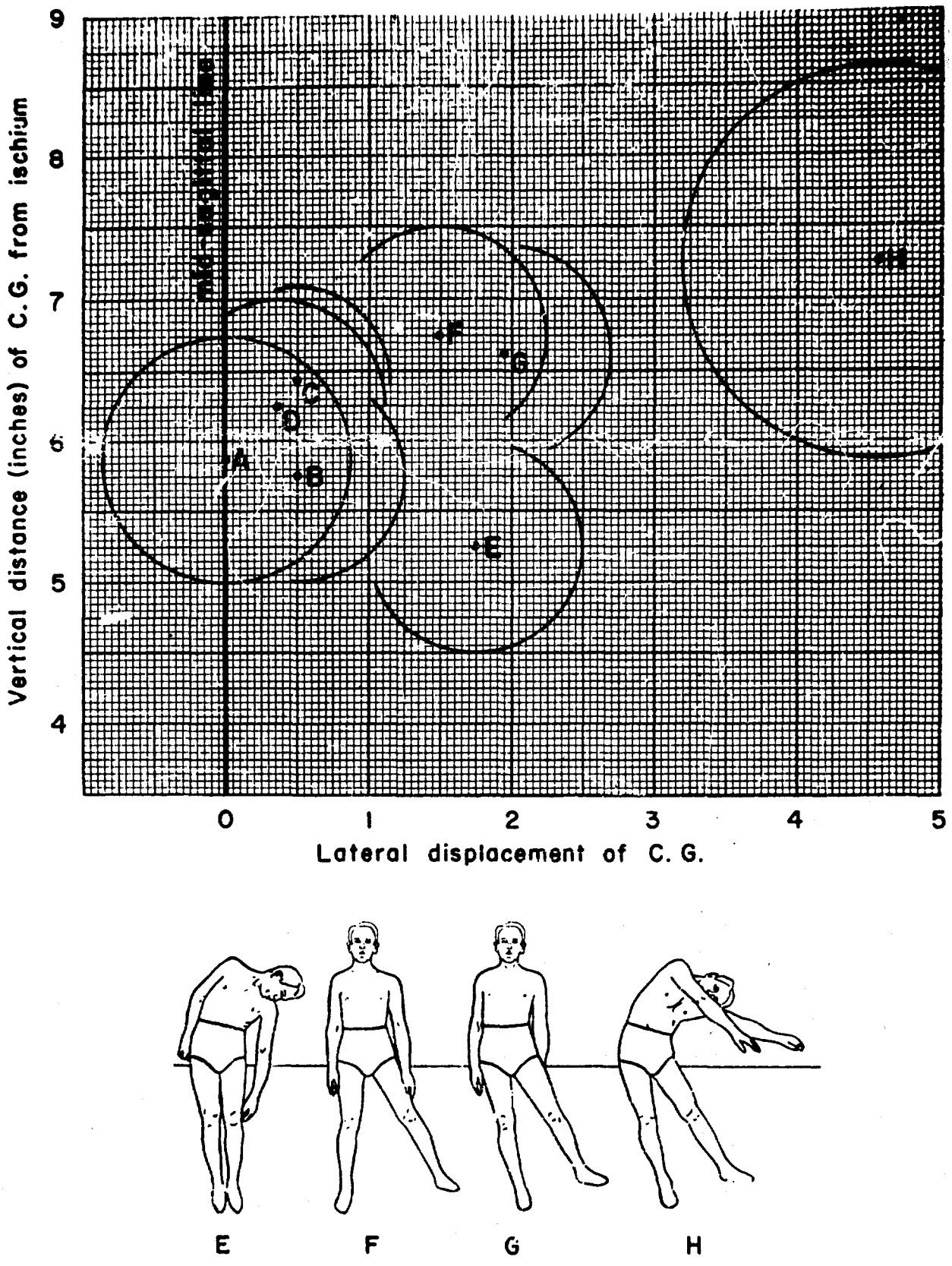


FIGURE 11. Displacement of C. G. by lateral movements (pelvis remaining fixed in one position).

TABLE X

Displacement of Body C. G. by Cephalad Movements

	Body Position	Location of Av. C. G.	Horizontal & Vertical Range For Subjects
A.	Body standing straight	(5, 5⅜)	± ⅜"
B.	Both arms extended over head	(5⅜, 8⅛)	± ⅝"
C.	Both legs in maximum position toward head	(10⅜, 15)	± 1½"
D.	All body parts in maximum cephalad position	(11⅛, 17⅜)	± 1⅝"

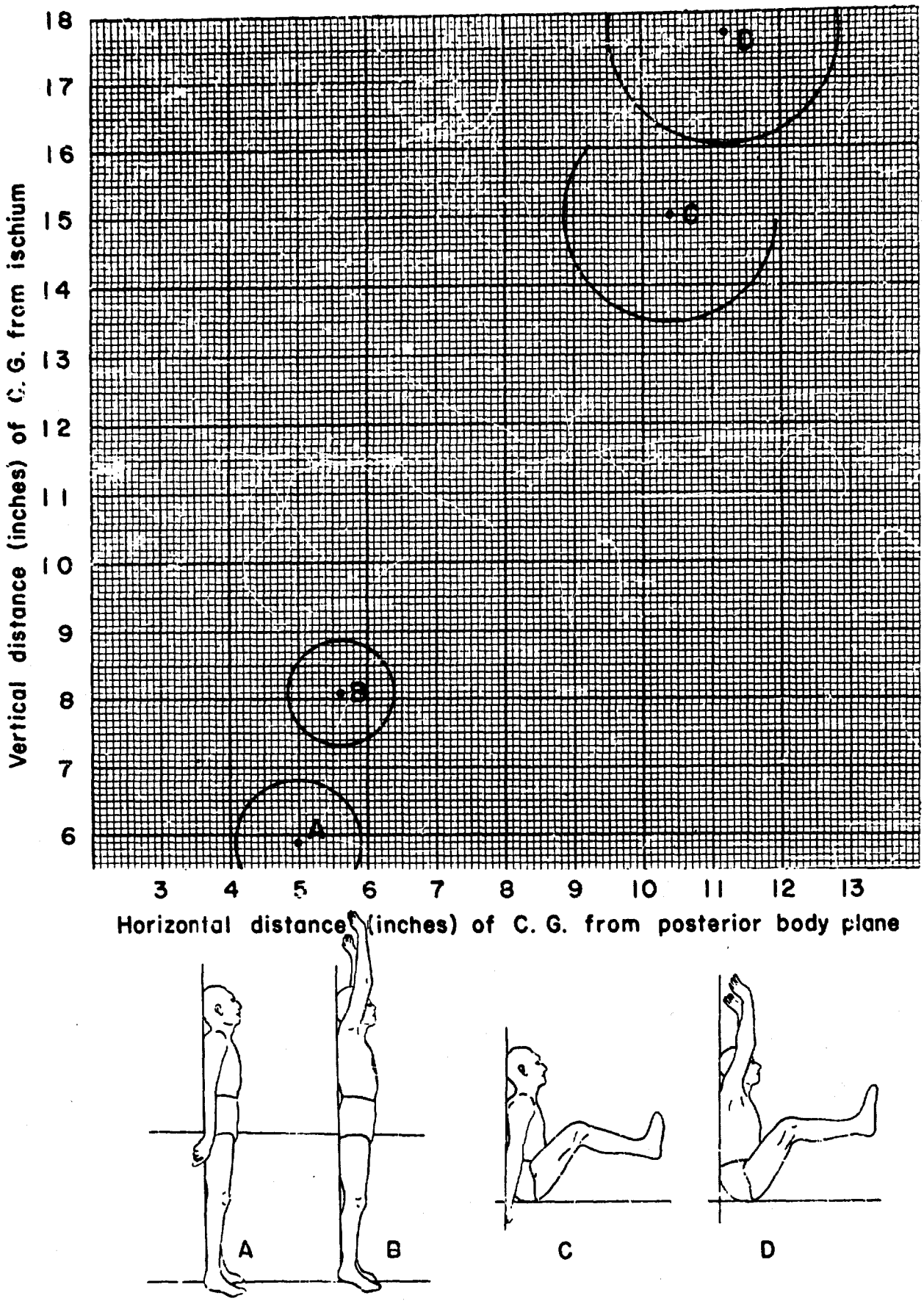


Figure 12. Displacement of body C. G. by cephalad movements.

TABLE XI
Displacement of Body C. G. by Caudad Movements

Body Position	Location of Av. C. G.	Horizontal & Vertical Range For Subjects
A. Body standing straight	(5, + 5%)	± ¾"
B. Trunk and head in maximum flexion toward feet	(7%, – %)	± 3¾"
C. Trunk, head and arms in maximum position toward feet	(10%, – 4%)	± 1¾"

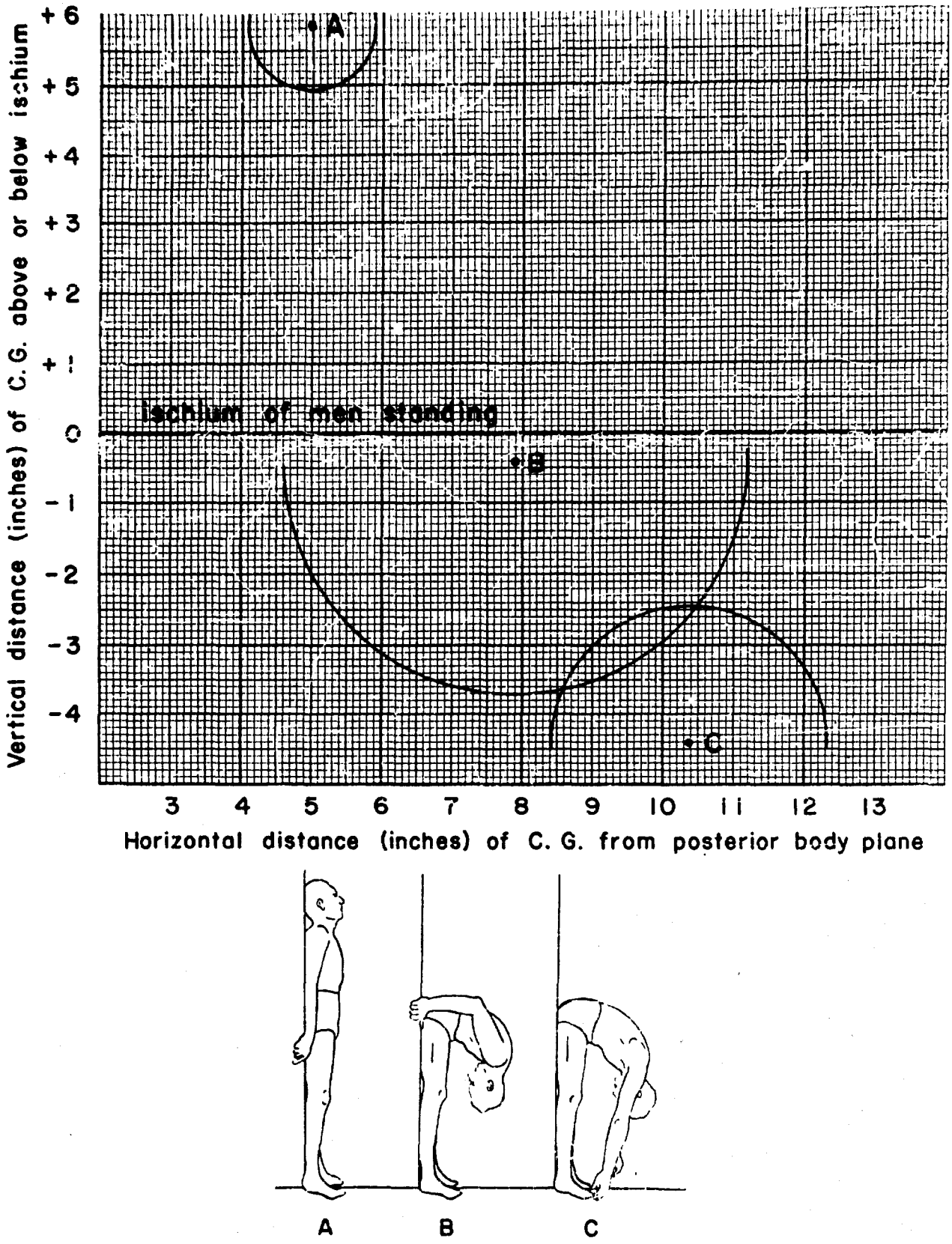


FIGURE 13. Displacement of body C. G. by caudad movements.

TABLE XII

Displacement of C. G. by Abduction of Arms and Legs

Body Position	Location of Av. C. G.	Vertical Range For Subjects
A. Standing, body straight	(0, 5⅝)	± 1/16"
B. Both arms abducted	(0, 7-1/16)	± ⅛"
C. Both legs abducted	(0, 6⅝)	± ⅛"
D. Both legs and both arms abducted	(0, 8¼)	± ⅛"

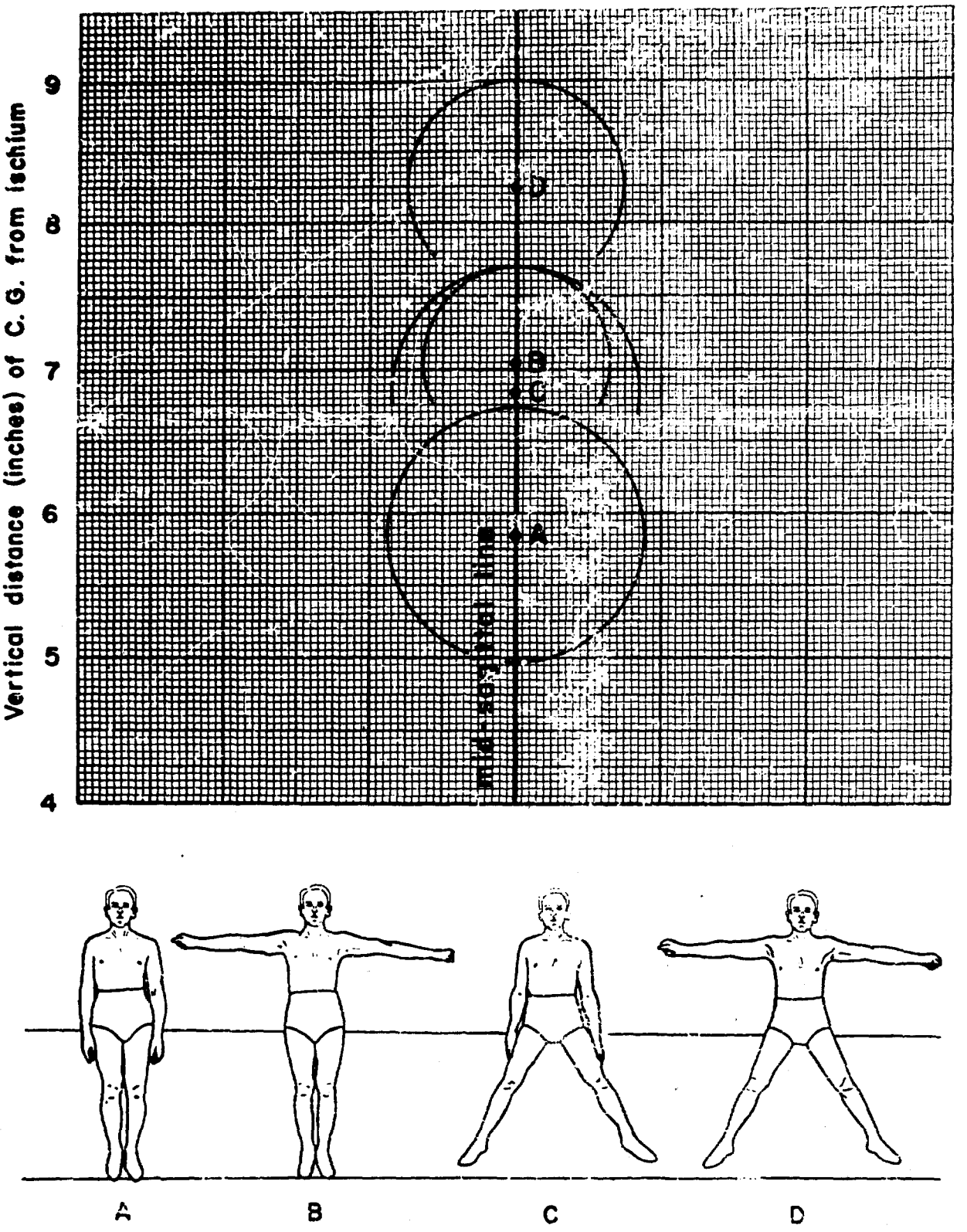


FIGURE 14. Displacement of body C. G. by abduction of arms and legs (pelvis remaining fixed in one position).

TABLE XIII

Displacement of Body C. G. by Abduction of Arms and Legs as Measured from Floor Level

	Body Position	Location of Av. C. G.	Vertical Range For Subjects
A.	Body standing straight	(0, 38¾)	± 1⅛"
B.	Standing, both arms abducted	(0, 39⅜)	± 1⅛"
C.	Standing, both legs abducted	(0, 36⅛)	± 2¼"
D.	Both arms and both legs abducted	(0, 37⅝)	± 2⅛"

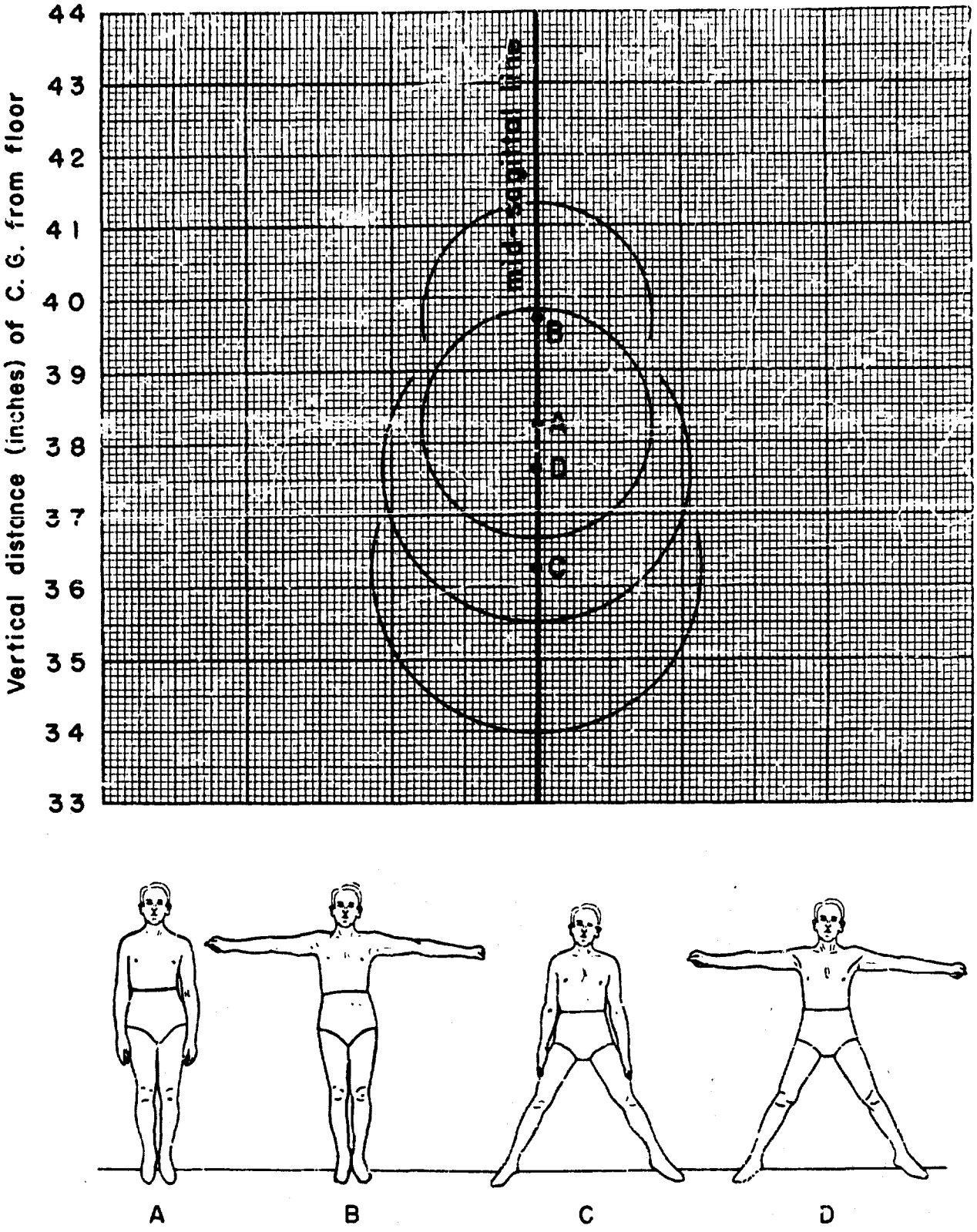


FIGURE 15. Displacement of body C. G. by abduction of arms and legs as measured from floor level.

TABLE XIV

Displacement of C. G. by 20 lb. Back Pack
(C. G. of Pack 18⅝" above ischium, 6" Back)
in Sitting and Standing Positions

Body Position	Location of Av. C. G.	Horizontal & Vertical Range For Subjects
A. Sitting without pack	(8⅝, 9⅝)	± 1⅛"
B. Sitting with pack	(7⅞, 10⅝)	± 1⅛"
C. Standing without pack	(5, 5⅝)	± ⅝"
D. Standing with pack	(3⅝, 7¼)	± ⅝"

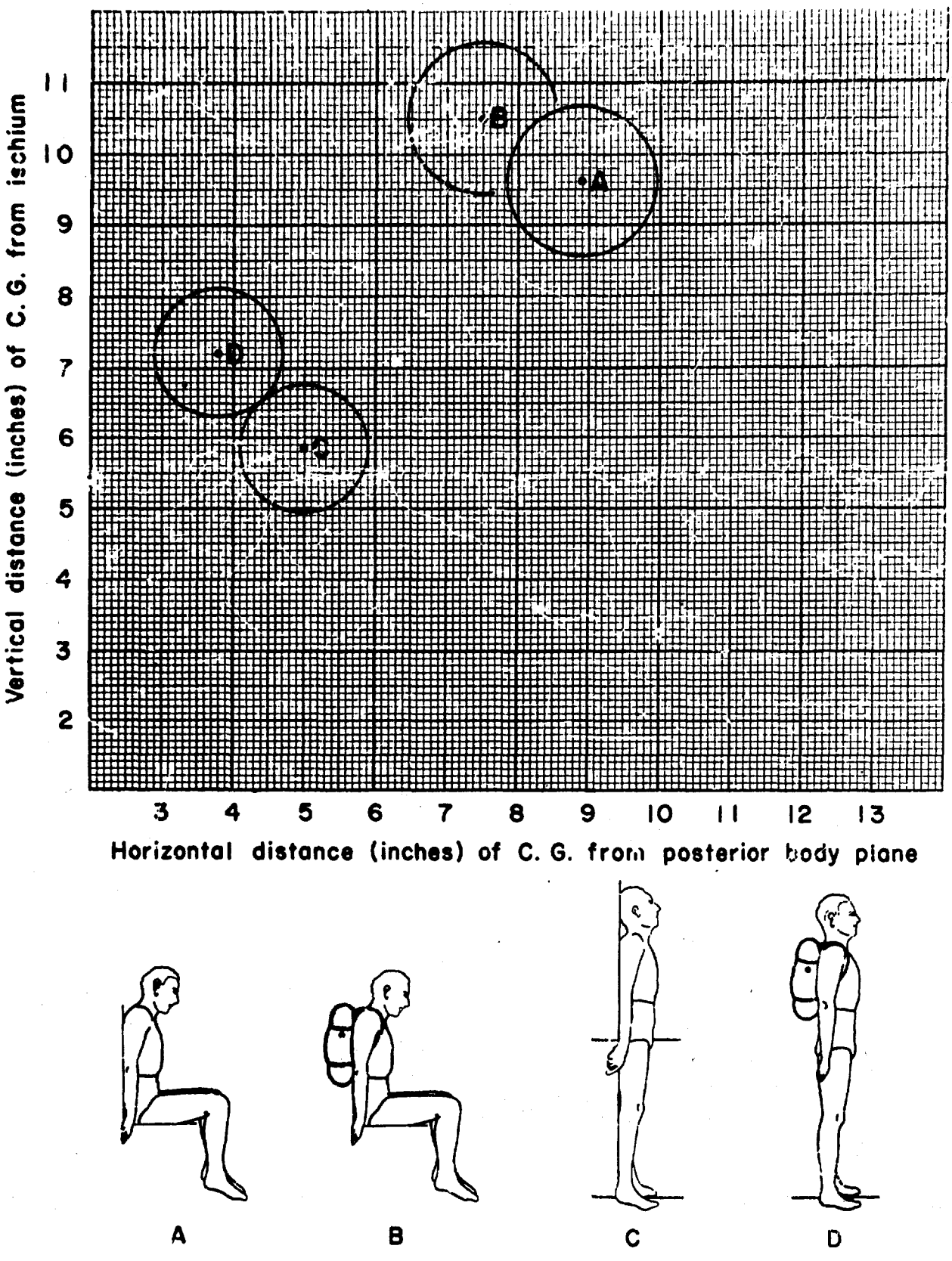


FIGURE 16. Displacement of C. G. by 20 lb. back pack (C. G. of pack 18½" above ischium, 6" back) in sitting and standing positions.